CEREAL SMUTS AND THE DISINFECTION OF SEED GRAIN

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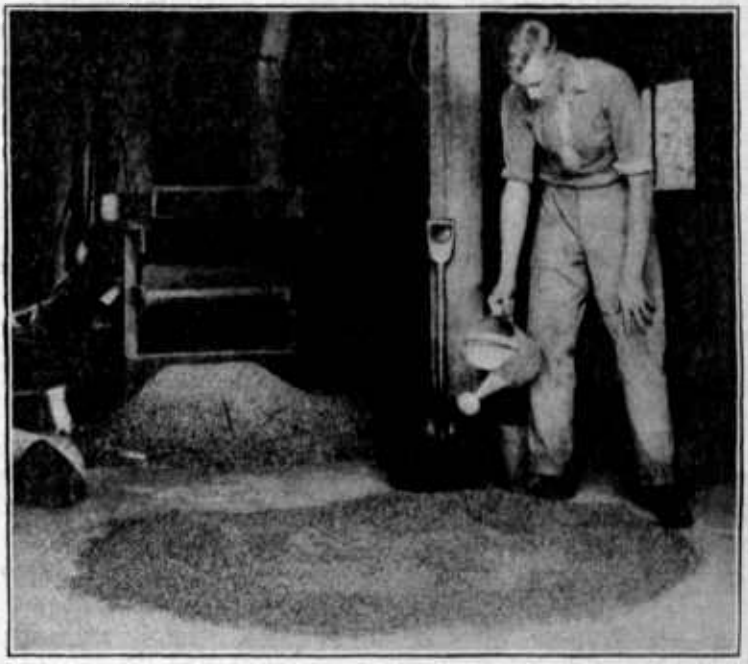

FARMERS' BULLETIN 939

UNITED STATES DEPARTMENT OF AGRICULTURE

Contribution from the Bureau of Plant Industry
WM. A. TAYLOR, Chief

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THIS BULLETIN is published for the purpose of providing a condensed but complete source of up-to-date information for practical use in controlling cereal smuts by means of the most generally approved methods for the disinfection of seed grain. It will be of use to the farmer and will serve particularly as a basis for the development of the ever-increasing extension work along this line.

Corn, wheat, rye, barley, oats, sorghum (including kafir and broom corn), and millet smuts are described and illustrated with photographs. There are at least two different kinds of smut which attack each of these cereals and, generally speaking, do not occur on any of the others. Most of them, but not all, are readily prevented.

When using formaldehyde the soaking process should be followed in the case of wheat, barley, and the sorghums. Sprinkling, or sometimes dipping, is more easily done and hence more generally used than soaking, particularly for oats.

Copper sulphate (bluestone) is not recommended for general use, particularly with barley and oats. It has one advantage over formaldehyde, however, in preventing in some degree infection from the soil in case the field has become contaminated. Such soil infection does not occur to any notable extent except in the wheat fields of the Pacific Northwest. Seed grain must be limed after treatment with copper sulphate if injury is to be avoided.

Treatment of seed grain with hot water is chiefly useful in preventing the loose smuts of barley and wheat. These can not be controlled by any other method.

Treating the seed to disinfect it may injure its germination. Such injury can usually be avoided by careful procedure, but it is never safe to sow treated grain without first testing it for germination and increasing the rate of sowing as required. This will result in the best stand of the most vigorous plants obtainable from the seed used.

Disinfecting seed grain will prevent certain diseases other than smuts (but not rusts) and thus may increase the yield even more than would be indicated by simply replacing the smutted with sound grain.

CEREAL SMUTS AND THE DISINFECTION OF SEED GRAIN.

CONTENTS.

DESCRIPTION OF THE CEREAL SMUTS.

THE KINDS OF SMUT are as numerous as the kinds of grain, and they differ from each other as essentially as do the different cereals, such as wheat, oats, barley, and rye. These smuts are fungous parasites. They are minute colorless plants of threadlike structure, which, with few exceptions, are able to enter the seedling grain plants just as they start, grow up within the "host" plants thus attacked, and there remain unseen until the heads of grain appear. At this stage the heads of diseased plants are found to be partially or wholly destroyed and replaced by masses of dark-colored fungous spores, the so-called smut. These spores are too small to be seen individually with the naked eye. In each visible smut mass there are thousands, or even millions, of them. They serve to propagate the smut in the next crop by getting on or in the seed, where they are at hand to begin growing again along with the grain when it is planted.

A few of the cereal smuts do not follow this rule of reproduction, and in such cases it is generally more difficult to prevent their attack.

CORN SMUTS.

Of the few smuts for which no specific method of control is known, the common smut of corn (fig. 1) is the most noteworthy. The disinfection of the seed fails to control this parasite, for the reason that it lives over winter in the soil, or sometimes in manure, rather than on the seed. During the growing season the germs of the disease are carried by the wind from the soil where they develop to the growing plants. Falling on the leaves, they are washed down on the young, tender parts in which they can produce the disease

later on. Diseased parts are always much swollen and are eventually transformed into the soft masses of smutted tissue which produce the spores of the parasite.

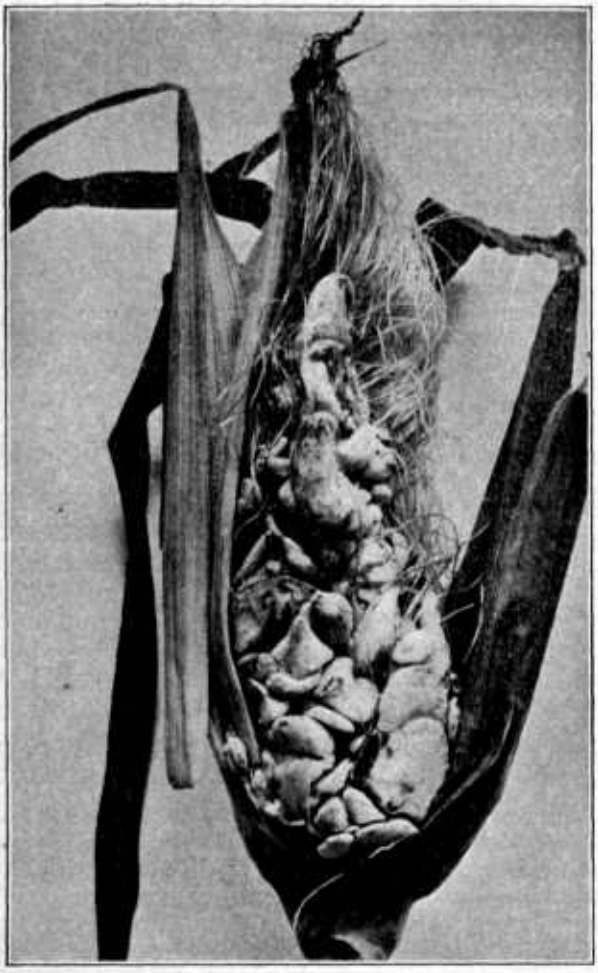

FIG. 1.—Common smut of corn. Smutted ears like the one here shown are common in the fields of the western Plains areas and also on sweet corn. This smut may occur on any part of the plant, though it is generally found in the ear buds on the lower part of the stalk. In Mexico the young smutted parts, which are sweet and tender before they turn black, are used for food.

It has been claimed that spraying the plants is partially successful in eliminating corn smut, but no practicable method has been developed. Where the farming methods are intensive, as with sweet corn, the disease may be partly controlled by cutting and burning all smutted stalks. Rotations are advisable, for continuous cropping to corn undoubtedly increases the losses from smut.

Somewhat like the common corn smut is the head smut (fig. 2). It occurs more frequently on the grain sorghums or on broom corn (p. 14) than on corn, but is not common on either crop. It can not be controlled by disinfection of the seed.

SMUTS OF WHEAT AND RYE.

Three different kinds of smut occur on wheat and rye: Bunt, or stinking smut, loose, or naked, smut, and stem smut. Bunt (fig. 3) is common in wheat, but it is not known to occur on rye in this country. Loose smut (fig. 4) is fairly common, though not often

serious in wheat; in rye it is extremely rare. In America stem smut is confined to rye (fig. 5); in Australia it occurs on wheat and is known as flag smut. It will be seen that, as they occur in the United States, these three kinds of smut are practically confined each to one or the other of the two crops and that they are therefore not the same for both of these cereals. It has, indeed, been found to be a general rule that the smuts of one crop do not attack any other crop.

Ordinarily all the smuts of wheat and rye can be prevented by disinfecting the grain before sowing it. Their individual peculiarities, however, require consideration in order that the necessary differences in treatment and the difficulties likely to be encountered may be understood.

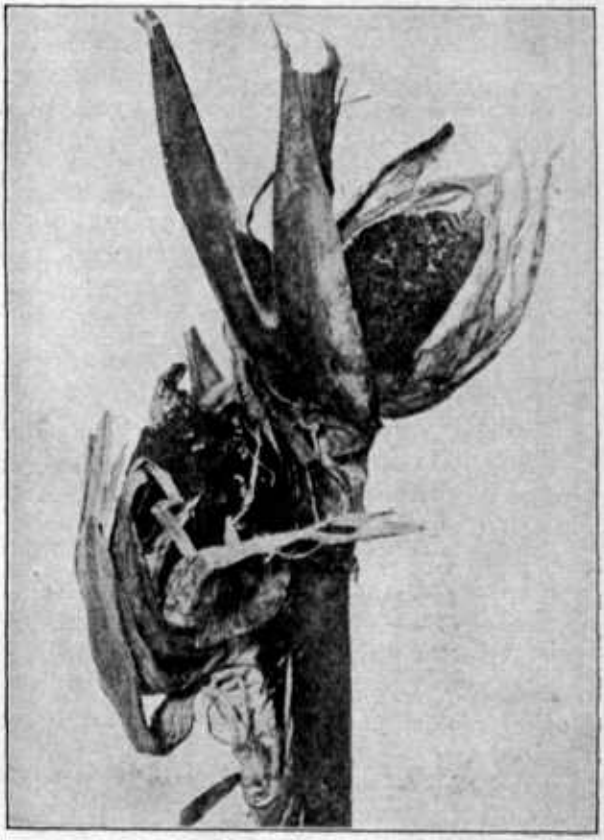

FIG. 2.—Head smut of corn, showing the characteristic destruction of all the ears produced. The tassel is also almost invariably destroyed, but other parts of the plant are seldom attacked. This smut is rare in America. (Illustration from an Australian photograph by D. McAlpine.)

BUNT, OR STINKING SMUT, OF WHEAT.

Two different species of fungi may cause bunt, or stinking smut. One of these, *Tilletia tritici* (fig. 3, on the right), occurs abundantly in the Pacific Northwest, where it causes exceedingly heavy losses. The other, *Tilletia laevis* or *foetens* (fig. 3, on the left), occurs rather commonly in the eastern United States. In Michigan, where both occur, the farmers call the first "low smut" and the second "high smut," because of a difference in the height of the affected plants. While the two kinds have been found to differ also in other particulars, they are generally considered to be so nearly alike that for practical purposes they will here be discussed together.

Before heading, smutted plants of either kind are practically indistinguishable from healthy ones. Even when the heads appear, the disease is not, with most varieties of wheat, at once evident except to the practiced eye. The smutted heads are of a distinctly darker

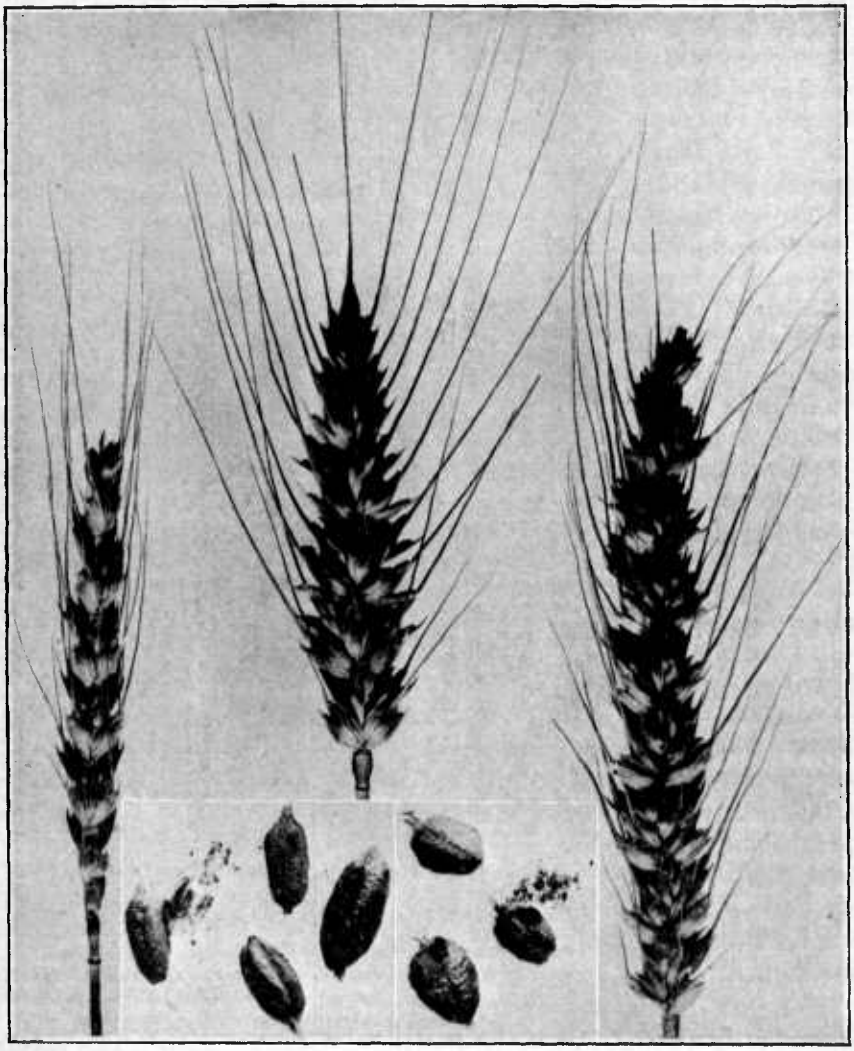

FIG. 3.—Bunt, or stinking smut, showing the two different kinds on Red Rock winter wheat from Michigan, with a sound head in the center for comparison. Smutted kernels, with a sound kernel in the center, are shown below. In the field the stalk bearing the head on the right would be very much shorter than the other two. Not all varieties are affected in just this way, however.

green color than sound ones, and the stalks usually are shorter. From heading time infected fields may sometimes be detected at a considerable distance to the leeward by the disagreeable odor from the smutted kernels, resembling decayed fish. As the crop matures,

the smutted heads, though standing more erect on account of their lighter weight, usually appear better filled than the sound heads. The chaff is spread widely by the swelling of the enlarged, false kernels, and the beards are frequently deformed and brittle. These false kernels, or smut balls, give the heads a dark color, due to their content of greasy, black spore powder. When thrashed, this smut powder is plentifully distributed on the grain, and if the spores are not killed they will infect the next crop if this grain is used for seed. Since the spores in unbroken smut balls can not be killed readily, the seed must be fanned to remove them or they must be washed out in the process of disinfecting.

FIG. 4.—Loose smut of wheat (center) showing also a sound head (left) and a naked stem of a smutted head as it appears at harvest time (right). This smut can not be prevented by formaldehyde or other chemical disinfectant.

The odor and color of the smut seriously affect the thrashed grain for milling purposes, so that it must be scoured clean by special processes. The dockage in price on this account is serious at times, particularly in sections where the mills are not adequately equipped with scourers and washers. The contamination of the grain as regards both quantity and character of smut depends largely on its condition as to maturity and moisture at the time of cutting and thrashing, and is perhaps also dependent upon the variety of wheat and the kind of bunt, though these conditions have not been well determined. If only a few smut balls are left in the grain after thrashing, almost all of these may be removed by careful fanning. On the other hand, if the smut is so smeared over the grain as to make it difficult to clean, or if, as frequently happens in badly smutted crops, a number of partly diseased kernels are present, the market value of the crop will be much lowered. Specific designation of smutty wheat as such, when offered on the market, is required by the regulations recently promulgated under the Grain Standards Act.

In some sections where combined harvesters are used, a method for avoiding the serious contamination of the thrashed grain from a smutted crop is sometimes employed by skilled operators who take advantage of the fact that the diseased stalks are shorter than the healthy ones. The sickle bar is so adjusted from time to time that

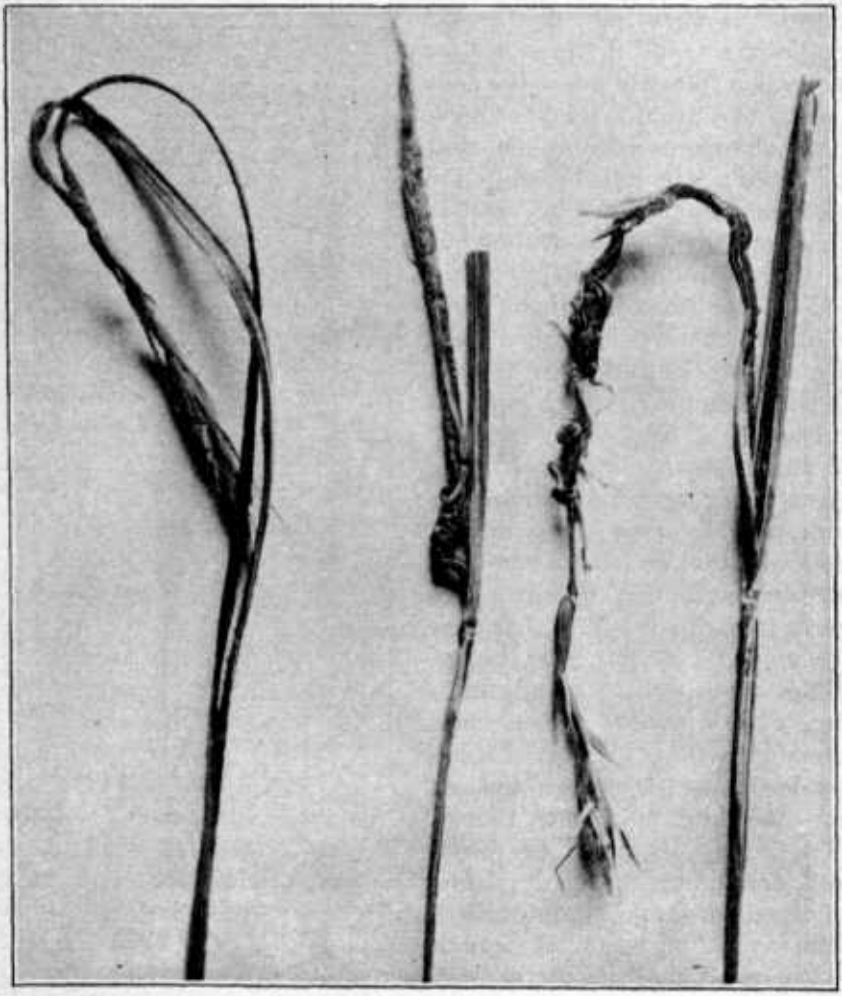

FIG. 5.—Stem smut of rye. Note how the stems are split and twisted and the heads distorted. The losses from this disease until recently have been underestimated. (Specimens collected in Minnesota by Stakman and Levine.)

the sound heads are skimmed from the crop, so to speak, thus leaving the smutted ones on the field with the straw. This procedure is especially feasible where the so-called low smut is prevalent, and in connection with continuous cropping to winter wheat it is partly responsible for the difficult situation as to soil infestation which has

arisen in the Pacific Northwest. With continuous cropping to wheat, infestation of the soil would also occur to some extent where self-binders are used, for the straw of smutted plants is frequently so brittle that many of the heads are broken off when hit by the reel; also, in the case of the low species of bunt, the straw is generally too short to be bound into the bundles and, though cut, the heads fall out and are left on the field.

In certain areas, particularly that known as the Palouse district of eastern Washington and northwestern Idaho, disinfection of the seed, usually wholly effective elsewhere in preventing bunt, is of comparatively little avail because of the very general infestation of the soil. Even virgin soils in the neighborhood of wheat fields will not grow a clean crop, so general does the infection become from the millions of wind-blown spores set free at harvesting and thrashing time (fig. 6). The influence of this soil infestation is particularly noticeable in the

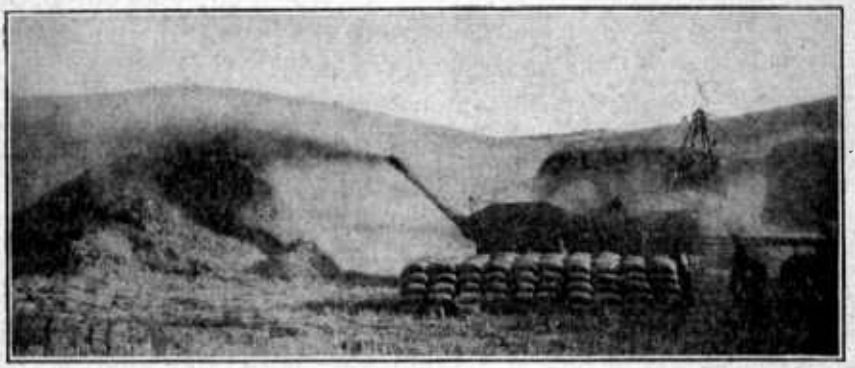

FIG. 6.—Thrashing a smutted crop in the Pacific Northwest. It is not surprising that smut showers, occurring in the vicinity of these operations, make the production of a clean crop of fall-sown wheat a difficult matter.

case of winter wheats, especially when sown on land where a thrashing outfit has stood. Also, since the prevailing winds in the Palouse country are from the southwest, the disease is generally worse on north and northeast slopes where the spores from the "smut showers" have settled in larger numbers. Most of the free spores (i. e., those not in unbroken smut balls) are killed during the winter, however, particularly if the seed bed is thoroughly worked over in the autumn. On this account efforts have been made to evade the disease by the thorough cultivation of summer-fallowed fields and by resuming the cultivation of spring wheats, although the latter do not generally yield as well as the winter varieties. Early sowing has also been recommended, since experience has shown that infection is usually much reduced thereby. If the seed is to be sown late, late plowing must also be practiced in order to bury the spores which have fallen on the land during the harvesting and thrashing season. It has been

suggested that some method of soil treatment at seeding might be devised to remedy the situation, but experiments which have been conducted along this line at the Washington State Agricultural Experiment Station have not been encouraging. In addition to these other methods, it is probable that much may yet be accomplished through the development of resistant varieties of wheat. None of these procedures, however, can be more than partially successful so long as an undiversified cropping system is followed. Crop rotation is undoubtedly an essential step in the solution of the bunt problem of the Pacific Northwest.

The losses from bunt in the United States are to be reckoned not only in the reduction in yield, which amounts to about 25,000,000 bushels annually, and in the dockage for smutty grain, probably totaling some $10,000,000 each year, but also in the explosions which sometimes occur during threshing. The oily nature of the spores makes them extremely combustible when beaten up into a dust. In the State of Washington many thousands of dollars have been lost in a single county in one season as a result of these explosions.

LOOSE SMUT OF WHEAT.

The loose smut of wheat (fig. 4) is distinctly different from most of the other cereal smuts and requires a different method of treatment for its control. Unlike the bunt of wheat, the diseased head bears little resemblance to a sound head. Except for the stem it is totally destroyed, the grain and chaff being replaced by a black, sooty mass. The spores begin to sift out of this mass almost as soon as the head pushes out of the boot and are carried by the wind to neighboring heads, which are in bloom at this time. They lodge between the glumes, or chaff, where, under favoring conditions, they start growth immediately and penetrate the newly forming grains. When these grains ripen they can not be told from sound ones, but they nevertheless contain the germs of the disease. When such an infected seed germinates, the smut plant within starts growth at the same time and develops within the growing grain plant, as already described (p. 3).

The fact that the loose-smut plant has already established itself within the mature seed makes it more difficult to eliminate without injury to the seed than those smuts which are present with the seed only as spores on the outside of the grain. The disease can be prevented, however, by the hot-water treatment, described on pages 23 and 24, provided the grain has been soaked long enough to give the heat a better chance to penetrate and act upon the smut germ.

The loose smut of wheat occurs in practically every field of wheat. The loss from this cause does not commonly exceed 2 per cent of the crop and is usually much less, although fields have been reported where fully one-fourth of the heads were destroyed.

STEM SMUT OF RYE.[1]

The presence of stem smut of rye (fig. 5) generally becomes evident as soon as the stalks begin to shoot up from the stool. As the diseased parts develop, they appear more or less swollen and distorted and of a darker color than the natural green. Later, the swelling becomes somewhat reduced and black spore masses form inside the smutted tissues, usually in long, bluish streaks, which eventually cause the stem to split and twist. The spores are also occasionally formed in the head or leaves. The straw is often so twisted and the stalks so stunted that the smutted plants are scarcely noticeable at harvest. For this reason they are so often overlooked that the rather serious losses which frequently occur in rye-growing sections have until recently been very much underestimated.

The smutted plants are in part harvested and thrashed with the crop and in part left on the ground. In both cases, but particularly in the former, they become a source of disease in the succeeding crop, for, just as in the case of bunt in wheat, the seedling may become infected from spores on the seed or in the soil. Where the disease is to be prevented, therefore, rye should not be grown in successive seasons on the same land, and the seed must be treated in the same manner as wheat for the prevention of bunt.

SMUTS OF BARLEY.

There are two smuts peculiar to barley which from the practical point of view correspond closely to the bunt and loose smut found on wheat in the United States. The head of barley affected with covered smut (fig. 7), however, has no odor, and it is more completely destroyed than a bunted head of wheat, for the chaff of the barley is generally also smutted and the beards are deformed. The diseased heads have a dark, gray color when ripe, are usually borne on shorter stems than the rest of the crop, and appear later than the sound heads. Frequently they scarcely succeed in emerging from the boot. When thrashed, they break up, and the spores are spread through the seed, thus contaminating it for another season. Those broken pieces, or chunks, which can be seen in the thrashed grain, should be removed by fanning before attempting to disinfect the seed.

The loose smut of barley (fig. 8) very closely resembles that of wheat, and the reader may be referred to the description of the latter (p. 10) as giving a practical understanding of both.

The smuts of barley can be found in almost any barley field and frequently cause losses of 5 to 10 per cent. Cases have recently been observed where one-fourth to nearly one-half of the crop in a field was destroyed by the loose smut alone.

[1] The reader is cautioned not to confuse this disease with the stem *rust*, for which no remedy is known.

SMUTS OF OATS.

The loose and covered smuts of oats (figs. 9 and 10) differ somewhat in external appearance, as their names would indicate. They are also distinguishable from each other by the appearance of the spores under the microscope. The loose smut is quite conspicuous at

FIG. 7.—Covered smut of barley, showing a smutted head and, for comparison, a sound barley head. When thrashed, the smutted heads break up into chunks, which must be removed from the grain if the disinfection process is to be thorough.

FIG. 8.—Loose smut of barley, showing early and late stages. This smut more closely resembles the loose smut of wheat (fig. 4), both in appearance and in method of attack, than that on oats (fig. 9). In spite of the similarity in appearance these three loose smuts are entirely different, i. e., they will not grow on any other crop than the one on which they were produced.

heading, but is mostly scattered by wind and rain before harvest. On account of the shorter stems, neither kind is very noticeable in a field from a short distance. The smutted heads can usually be located in a green field, however, by the dead upper leaf.

The differences between the two smuts of oats, though they seem at first to correspond to those which distinguish the two smuts of barley (p. 11), are not known to be of any practical significance.

FIG. 9.—Loose smut of oats, showing a smutted head, with a sound oat head for comparison. In spite of the ease with which they may be controlled, this and the covered smut of oats (fig. 10) have been taking a toll from the American oat grower which would feed all the horses attached to 20 army corps of 100,000 men each, or nearly a million head.

FIG. 10.—Covered smut of oats.

Both of the smuts of oats are preventable by the ordinary methods of seed treatment, since in both cases the spores in the seed oats, which serve to carry the disease over from one crop to another, may be killed without injuring the seed.

In spite of the ease with which losses may be prevented, the smuts of oats have probably been responsible for greater losses, year in and year out, than any other pre-

ventable crop disease in the United States. This is because they are inconspicuous at harvest and usually do not in any way injure the quality of the thrashed grain, so that they have been very generally considered unimportant. Indeed, growers frequently insist that they have no smut in their oats when, as a matter of fact, they are losing annually from 5 to 25 per cent or more of their crop. This widespread neglect, coupled with the fact that oats are so largely grown, has made the average yearly loss the country over amount to 50,000,000 bushels or more. The work of the county farm bureaus, established with the aid of funds provided by the Smith-Lever Act, has done much to reduce this loss in the last few years.

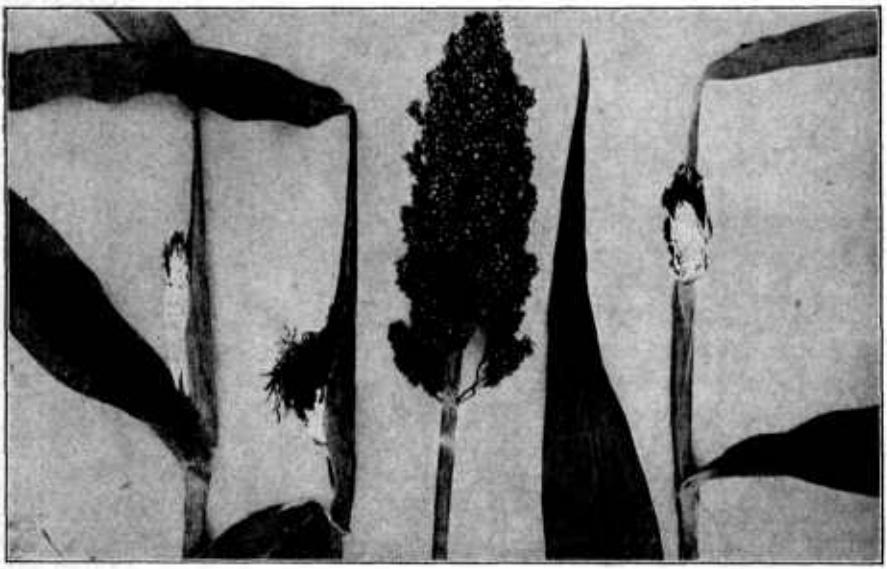

FIG. 11.—Head smut of sorghum on Sumac sorgo, showing three smutted heads, with a sound head of the same variety, for comparison. The young smutted heads are considered a delicacy by certain African tribes.

In the south-central Mississippi Valley the highly resistant character of Burt oats (also called Early Ripe and May oats), which are adapted to that area, has enabled many growers to avoid losses without treating the seed.

SMUTS OF SORGHUM.

The sorghums, including the different kinds of sorgos, or sweet sorghums ("cane"), Sudan grass, kafir, milo, feterita, and broom corn, are subject to a number of smut diseases, of which three are known in this country. The head smut (fig. 11) has already been mentioned (p. 4) as uncommon, and since it can not be prevented

by any means other than those suggested for corn smut (p. 4), nothing further need be said about it here.

There are also two kernel smuts (fig. 12), which differ from each other in no essential way. They are like the smuts of oats in that one is loose and the other covered and also in that both usually destroy each kernel separately. As with oats, the treatment of the seed is an effective remedy.

The damage done is frequently serious, particularly in kafir and broom corn. In the latter crop the destruction of the seed would not be of much consequence, but the smut also affects the brush, not only by making it dirty, but also by causing a tendency to coarseness and the formation of a central stem in the head. Kansas authorities estimate a loss of 5 per cent in the kafir crop in average years. Fortunately, milo, feterita, and a few other varieties of grain sorghum have thus far proved to be extremely resistant, and smut seldom occurs in them.

FIG. 12.—Loose and covered kernel smuts of sorghum on kafir, showing two sound heads of kafir (center) for comparison. Both of these smuts are readily preventable by disinfection of the seed.

MILLET SMUTS.

The smuts of millet are somewhat similar to those of the sorghums. The kernel smut of millet (fig. 13), however, occurs only on the spiked varieties (the foxtail millets), while the head smut, which resembles that on sorghums in appearance, is peculiar to proso, or hog millet. The former is readily prevented by the same treatment as for the kernel smut of sorghums. The head smut has been very rarely found in the United States, and but little is known concerning it. Some writers in Europe have claimed that it, too, can be prevented by treatment of the seed.

METHODS OF DISINFECTION.

MATERIALS, APPARATUS, AND FORMULAS.

Three general methods for disinfecting the seed of cereal crops are commonly in use, namely, treatment with formaldehyde, with copper sulphate, and with hot water. Other fungicidal or germicidal methods or substances may be used, but are either poisonous, less efficient, less readily available, more expensive, or for some other reason are not

usually so satisfactory or so generally used. They will, therefore, not be considered here.

Whatever method is used, it is always profitable to clean and grade the seed thoroughly beforehand. Dirty sacks, bins, and machinery should be disinfected or scalded before using them for handling treated seed.

Formaldehyde.[1]

Formaldehyde, as usually sold, is prepared as a solution of formaldehyde gas in water. According to the United States standard of purity for interstate commerce, 37 per cent of the weight of the solution as sold must consist of formaldehyde gas. Some State laws require a 40 per cent solution. When these concentrated solutions are allowed to become very cold, a whitish substance, paraformaldehyde, will appear in them. This weakens the solution and, before using, it should be warmed until the paraformaldehyde disappears.

FIG. 13.—Kernel smut of millet (at right), with a sound millet head (at left) for comparison. This smut occurs only on the foxtail millets and not on proso (hog millet). It is not the same as the kernel smut commonly found on the foxtail grasses of the Eastern States.

A solution of formaldehyde in water when exposed to the air under ordinary conditions will become stronger, and hence more likely to injure the germination of the grain treated. Old solutions which have been used and have stood exposed for two or three days should therefore be discarded, not because they have lost their strength, but because they have gained in strength indefinitely and can not be brought again to proper strength for safe and dependable use.

Formaldehyde was discovered by Hofmann, a German chemist, in 1867, and has been used in disinfecting since 1888. In the United States it was first recommended for use on grains by Bolley, of the North Dakota Agricultural Experiment Station, in 1897. For use in preventing bunt in wheat, stem smut in rye, covered smut in barley, either of the smuts in oats, or the kernel smuts in sorghum (kafir, broom corn, etc.) and millet, it is very much the most convenient and effective fungicide known. It has the particular property of leaving

[1] Formalin is a term which has been much used to signify the commercial solution of formaldehyde. It has, however, been registered as a trade-mark by a German firm of chemists. For disinfecting purposes, the ordinary solution, which usually contains 5 to 10 per cent or more of wood alcohol in addition to the formaldehyde gas, is as good as the proprietary "Formalin."

no trace of its poisonous effect in the grain when dried. This, however, is not always an advantage (see p. 20).

The several methods of applying formaldehyde to seed grain are by (1) soaking, (2) dipping, (3) sprinkling, and (4) spraying. Except when using the first of these, all seed should be passed through a fanning mill and thoroughly cleaned before it is treated. This is particularly necessary with wheat and barley, and is always advisable even with the soaking process.

SOAKING.

With the possible exception of oats and rye, the thorough treatment of seed grain requires that, in addition to cleaning by fanning, it shall be soaked in an open vat or tub, so that it can be stirred, and the refuse rising to the surface, including unbroken, smutted kernels, can be skimmed off. Otherwise these false kernels, containing innumerable smut spores which are not injured by the treatment, become broken in subsequent handling and thus reinfect the seed grain before it is sown. Machines for the convenient and thorough performance of such a soaking process are on the market and will prove useful to large growers, particularly for use with wheat. Simpler and less expensive devices are shown in figures 14 and 15.

FIG. 14.—Simple apparatus for the soaking process, consisting of two half-barrel tubs, fitted with pine plugs and rope handles, and two sawhorses. The holes for the plugs are covered with screening. When the grain in the upper tub has been soaked long enough, the solution is drained into the lower tub and the grain spread out to dry. The position of the tubs is then reversed, more grain is poured into the solution, and the process repeated.

The period of soaking may be varied from little more than dipping, in which case the grain must afterwards stand wet in a pile, as in the sprinkling method (p. 19), to so long a soaking that the grain is thoroughly and uniformly disinfected when removed from the solution and may be immediately spread out to dry. In attempting to eradicate smut from a community, so as to avoid the necessity for treating the seed each year, this prolonged method should be used because of its thoroughness, even though it gets the seed so wet that it is troublesome to dry during cold or wet weather. A long period of

soaking is especially to be preferred in the case of barley, because in this way losses from loose smut (p. 11) and stripe (p. 27) are more or less controlled, and also in the case of the sorghum crops, in which the small quantity of seed required and the semiarid conditions under which these crops are generally produced make the drying of the seed a simple matter. As a rule, however, it is undesirable to wet the seed grain any more than is necessary. For this reason the longer periods shown in Table I are not recommended for general use.

The strength of the formaldehyde solution, expressed as dilutions of the commercial (37 to 40 per cent) preparation, and the periods of soaking which are recommended for the different grains are shown in Table I.

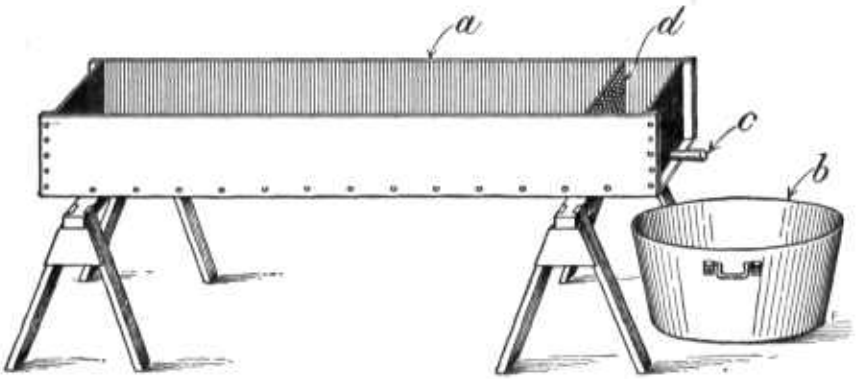

FIG. 15.—Simple apparatus for the soaking process, consisting of trough, tub, and sawhorses: *a*, Trough; *b*, tub; *c*, pine plug; *d*, perforated tin plate. The trough is filled two-thirds full with the solution and the grain added, stirred, and the floating refuse skimmed off. Drain the solution into the tub, shovel out the grain, replace the solution in the trough, and repeat the process.

TABLE I.—*Formulas for soaking treatment with formaldehyde.*

[Never use dirty sacks, bins, or machinery for handling treated seed without first thoroughly soaking them with strong formaldehyde (1 pint in 10 gallons) or scalding with boiling water. Read the section on seed injury, p. 24.]

Crop.	Dilution of solution.	Duration of treatment.	Remarks.
Barley	1 part in 320[a]	30 minutes to 3 or 4 hours.	Loose smut not wholly prevented.
Broom corn	1 part in 240[b]	2 to 4 hours	Head smut not preventable.
"Cane" (sorgo)	do	do	Do.
Corn			Treatment of seed does not prevent smut.
Emmer	1 part in 320	30 minutes to 1 hour	Loose smut not prevented.
Kafir	1 part in 240	30 minutes to 2 hours	Head smut not preventable.
Millet	do	do	Proso not included.
Oats	do	do	
Rye	1 part in 320	10 to 30 minutes	Rotate with other crops.
Spelt	do	30 minutes to 1 hour	Loose smut not prevented.
Sorghums	1 part in 240	2 to 4 hours	Head smut not preventable.
Sudan grass	do	do	Do.
Wheat	1 part in 320	10 to 30 minutes	Loose smut not prevented. See page 9, on soil infestation by bunt.

[a] Equivalent to 1 pint in 40 gallons, liquid measure.
[b] Equivalent to 1 pint in 30 gallons, liquid measure.

DIPPING.

In dipping, the seed grain, after thorough cleaning and grading, is usually placed in gunny sacks (seamless heavy cloth sacks are not satisfactory) which should be filled not more than half full and tied at the top. If the sacks are too full the grain can not be properly agitated so as to get it all thoroughly wet at the same time. After repeated dipping and agitation in the solution the sacks of grain are put where they will drain and dry enough so the seed will run freely through the drill. If not used within two hours (or at most over night) from the time of dipping, the seed should be spread out to dry and air, in order to stop the action of the formaldehyde. Wheat and rye are especially liable to injury if left wet too long.

This method is essentially only another way of carrying out the sprinkling method described below.

SPRINKLING.

The sprinkling method (see the title-page illustration) is almost a standard procedure for the treatment of oats and is also widely used for the other cereals. For the sorghum crops, where relatively small quantities of seed are concerned, the soaking process is to be preferred.

For sprinkling, the same strength of solution may be employed as for the soaking process (Table I), and the same precautions should be observed. Not more than a gallon of the solution will be required for a bushel of any kind of grain. Many use only half a gallon. Application is made with an ordinary sprinkling can while the seed is being shoveled over from one pile into another. The grain must be so well stirred that every kernel is thoroughly wet. It is then covered with sacks or other cloth wet with the formaldehyde solution and allowed to stand for a period before being spread out to dry or sacked for use. Oats and barley should remain wet in the pile for at least two hours or may be left over night. Wheat and rye, if treated by this method, are more likely to be injured by standing wet over night, but should be left covered for at least two hours.

SPRAYING.

The difficulty of drying the grain after treatment by the methods described above has recently been obviated by the use of a strong solution, in small quantity, which is sprayed on the seed grain in a very fine mist. This method has not been thoroughly tried with all the cereals, but its convenience commends it in practice, and it has proved satisfactory for oats in the Eastern States. A description [1] of the process is therefore given herewith.

[1] Haskell, R. J. The spray method of applying concentrated formaldehyde solution in the control of oat smut. *In* Phytopathology, v. 7, no. 5, p. 381-383. 1917.

As the seed is being shoveled from one pile to another, each shovelful is sprayed with a solution consisting of one part of 40 per cent liquor of formaldehyde and one part of water. This solution is used at the rate of 1 quart to 50 bushels of seed. A small quart sprayer is a convenient one to use for the purpose. After the oats are all treated in this way they are piled in a heap and covered with blankets, canvas, or sacks to confine the vapor. At the end of five hours the seed may be uncovered and planted. As formaldehyde vapor acts as an irritant to the mucous membrane of the eyes, nose, and throat, the sprayer should be held down close to the pile and a circulation of air should be provided.

With the ordinary quart sprayer, one stroke of the piston will give enough mist, if properly distributed, for each shovelful of grain.

Special apparatus for the uniform application of formaldehyde gas, preferably in a jet of steam or vapor, to large lots of grain in an elevator can be readily devised. Several devices for this purpose have been patented and would prove particularly useful where a "dry" treatment is almost imperative, as in treating flaxseed to prevent wilt. Strictly dry treatments have not been found successful, since disinfection with formaldehyde gas appears to require some moisture.

Copper Sulphate.

A definite method for the use of copper sulphate (bluestone or blue vitriol) in the treatment of seed grain was described by Prévost, in France, in 1807, and it seems probable that the use of this or other copper salts was first practiced many years earlier. With the introduction and improvement of other methods for the chemical treatment of seed grain, however, particularly the formaldehyde method, the use of copper sulphate, which had become quite general, has been discontinued in many sections of the United States. This has been largely the result of its greater cost [1] and greater injury to germination and the development of the seedling. Formaldehyde is also more convenient to use, because metal containers of any kind can not be used for copper-sulphate solutions, since they will become corroded and the action will at the same time weaken the copper-sulphate solution. Moreover, the treated grain can be used for feeding purposes when disinfected with formaldehyde, but not when copper sulphate is used.

Copper sulphate has one distinct advantage, however, because of the fact that as the solution dries it leaves on the seed a deposit of the copper sulphate, which acts as a protection against reinfection from the soil or other source. It is for this reason more generally used on wheat than on other cereals, particularly in those Pacific Coast States where bunt infestation in the soil is serious (p. 9).

[1] At this time (January, 1918) it has been some two years since copper sulphate sold for less than 10 cents per pound, and that only in carload lots. Small quantities can not be obtained for less than 25 cents per pound. This high price, coupled with the national need for conservation of compounds of both copper and sulphur, makes it especially desirable to avoid the use of copper sulphate for treating seed grain.

Soaking in an open vat or tub, dipping, or sprinkling—methods already described for the use of formaldehyde (pp. 17–19)—may also be used for the application of copper sulphate to seed grain. However, as noted above, the value of this treatment is chiefly dependent upon the fungicidal action of a more or less permanent coating of copper sulphate left on the seed, so that, inasmuch as the germination of the seed is likely to be injured, it is never desirable to leave the seed wet any longer than is necessary to get the surface of every kernel thoroughly wet with the solution, or, when soaking in an open vat, to remove the floating trash and smut balls. As soon as the application of the solution is completed, therefore, the grain should be dipped immediately in milk of lime, or sprinkled with it, to prevent injury to germination, and then spread out and raked over occasionally to hasten drying.

Solutions varying from 1 pound of copper sulphate to 5 gallons of water to 1 pound to 10 gallons are commonly used. The addition of common salt (sodium chlorid) to the copper-sulphate solution has been found to add considerably to its effectiveness, with no apparent increase in its tendency to injure the seed if lime is used afterwards. The salt is added at the rate of 1 pound for every pound of copper sulphate used.

To prepare milk of lime for use after the application of copper sulphate, slake 1 pound of quicklime and add enough water to make 10 gallons.

Hot Water.

Many variations of the use of heat for the prevention of smut, some of them of ancient origin, have been employed; but the standardization of the practice was not accomplished until Jensen, in Denmark, took up his studies of the hot-water process during the latter part of the past century. His methods, or such modifications of them as are believed to be most practicable, are here described under the following heads: (1) The short hot-water treatment, (2) the modified hot-water treatment, and (3) the long hot-water treatment, or pasteurization. The last two treatments are considered together, since one or the other is required in the case of loose smut in either wheat or barley.

THE SHORT HOT-WATER TREATMENT.

The short hot-water treatment will prevent only such diseases as are also preventable by chemical methods. While a certain amount of experience and equipment are necessary to its use, it has the advantage of general availability and cheapness. It is most useful for the treatment of the seed of the grain sorghums and broom corn, since higher temperatures may be used on these crops, and also because the relatively small quantity of seed needed may be uniformly and

effectively treated with greater facility than in the case of the smaller cereals. As compared with disinfection by formaldehyde or copper sulphate, this method may be used with less danger of injury to germination in the case of grain which has been cracked or scratched in thrashing. Details of the treatment required for the different cereals are given in Table II.

TABLE II.—*Formulas for the short hot-water treatment.*

[Never use dirty sacks, bins, or machinery for handling treated seed without first thoroughly soaking them with strong formaldehyde (1 pint in 10 gallons) or scalding with boiling water. Read the section on seed injury, p. 24. Keep the hot-water bath agitated, so that the temperature will be equalized throughout.]

Crop.	Temperature of water.	Admissible range in temperature.	Duration of treatment.	Remarks.
	°F.	°F.	*Minutes.*	
Barley	129	126 to 130	10 to 15	Loose smut not prevented.
Broom corn	140	134 to 142	10 to 12	Head smut not preventable.
"Cane" (sorgo)	140	134 to 142	10 to 12	Do.
Corn				Treatment of seed does not prevent smut.
Emmer	132	130 to 135	10 to 15	Loose smut not prevented.
Kafir	140	134 to 142	10 to 12	Head smut not preventable.
Millet	140	134 to 142	10 to 12	Proso not included.
Oats	132	130 to 135	10 to 15	
Rye	132	130 to 135	10 to 15	Rotate with other crops.
Spelt	132	130 to 135	10 to 15	Loose smut not prevented.
Sorghums	140	134 to 142	10 to 12	Head smut not preventable.
Sudan grass	140	134 to 142	10 to 12	Do.
Wheat	132	130 to 135	10 to 15	Loose smut not prevented. See p. 9 on soil infestation by bunt.

On the average small farm seed grain, when given the hot-water treatment, may be handled as follows: Provide at least two screen-lined or cloth-lined baskets holding about a bushel of grain each; two or three barrels or tubs, as large as are available, for water; a good thermometer; and a supply of boiling water. The grain is placed in a basket, which is filled not over two-thirds full and plunged into one of the tubs or barrels full of hot water at the temperature indicated in Table II. This temperature must be maintained as closely as possible by the addition of hot water as needed. Less difficulty will be experienced in doing this if the quantity of water used is large as compared with the bulk of grain being treated, and also if the grain is first plunged for a minute into a preliminary hot bath prepared in another tub at a temperature about 10 degrees lower than is required for the treatment.

At the end of the period of treatment the basket of grain is transferred to cold water in the third tub, so as to terminate the action of the heat. This procedure is unnecessary, however, if the grain can be spread out to cool and dry *immediately*. If the temperature of the bath has been lower than that shown in the second column of Table II the treatment should accordingly be prolonged a few minutes; while if it has been generally too high, a corresponding shortening of the period of treatment is necessary.

On farms or at central treating plants where steam is available the hot-water treatment may be much simplified by regulating the temperature of the bath with a steam jet placed in the bottom of the tub or vat used. A cloth or screen tied over the jet will prevent the noise caused by the injection of steam. Automatic regulation of the steam supply by a thermostat could be readily provided in a central treating plant without much expense.

THE MODIFIED AND THE LONG HOT-WATER (PASTEURIZATION) TREATMENTS FOR WHEAT AND BARLEY.

The treatment on the farm of all the seed for the season's planting by either of these methods for the prevention of the loose smuts of wheat and barley is not usually feasible. The prevention of these smuts, therefore, can be accomplished best by treating a small amount of carefully selected and recleaned seed and using this to grow seed for the ensuing season. Such a seed plat should be large enough to provide more than twice as much grain as will be necessary for farm seed the following fall or spring. This will provide for a reserve stock of seed and also for loss in cleaning and selecting. The isolation of this plat from smutted crops of the same cereal is absolutely necessary, not only from crops on the owner's farm but from neighboring farms as well. The plat should be watched at heading time for smut which may have escaped the treatment, so that affected plants may be promptly removed and burned.

The equipment and general procedure for treating grain by the modified and pasteurizing processes are essentially the same as for the short process (p. 22). The prolonged soaking which is necessary for the prevention of the loose smuts of barley and wheat (pp. 10 and 11) is accomplished in different ways in the two methods; in the one, by soaking in cold water before treating with hot water, and in the other by using a lower temperature in the bath and prolonging the treatment.

The presoaking in the modified process should be continued for 4 to 6 hours. If the water used and the weather are warm, the period of soaking should be shorter than when using cold water during cool weather. After presoaking, the grain is handled as in the short hot-water process (p. 22) and is treated as follows: For wheat, 129° F. for 10 minutes (admissible range, 124° to 131° F.); for barley, 126° F. for 13 minutes (admissible range, 124° to 129° F.). Greater care is necessary in this process than in using the short hot-water treatment, for the danger of injury to germination is considerable. The preliminary hot bath and subsequent cold dip (p. 22), to insure that the treatment shall begin and end promptly as intended, can not be omitted in this modified procedure, and thorough agitation of the bath is essential. The period of treatment, moreover, must be short-

ened or lengthened as the temperature rises or falls below the definite point assigned—129° F. for wheat and 126° F. for barley.

The long hot-water treatment or pasteurization method may make use of the same kind of equipment as the other hot-water methods. Only one tub or vat is required, however. The treatment for wheat and barley is the same, i. e., 3 hours at 113° F.; admissible range, without change in the duration of the treatment, 111° to 115° F. In order to keep the bath agitated so as to equalize the temperature throughout, it is suggested that the basket or sack containing the grain be suspended by a rope from a beam or the limb of a tree, so it will hang in the water. It can then be moved about readily, and the rope can be twisted so that it will continue to turn for a time without attention. The advantages of this method lie in the greater safety to germination, in the greater certainty of prevention, and in the use of but a single bath. It is difficult, however, though not at all impossible, to maintain an almost constant temperature for so long a time.

It has been found entirely feasible to vary the temperature for pasteurizing at will between wide limits (105° to 120° F.) provided the duration of the treatment is varied accordingly within a range of 1½ to 6 hours. The satisfactory use of this wide range, however, requires that some other method than guessing be employed to indicate the period of treatment required. An instrument for this purpose has been devised and successfully used experimentally in rendering this treatment safe and certain, but it is not at present so standardized that it can be produced for general use.

During the application of either of these processes for the prevention of the loose smuts of wheat and barley, the grain must absorb about one-fourth of its original weight in water. In most grain-growing districts it is therefore necessary, if the prevention of these smuts is to be undertaken on a commercial scale, that it be done in connection with a central treating station where artificial drying facilities with forced draft can be installed. In using such an artificial drier, care must be taken not to dry at temperatures so high as to injure germination. It will be safer not to use temperatures above 150° F. after the grain is surface dry. The grain itself should not reach a temperature above 140° F., and if the circulation of air is inadequate temperatures as low as 110° F. will be injurious if long continued.

SEED INJURY.

The difficulty of avoiding injury to the seed from treatment that is too severe or from improper drying after treatment has undoubtedly had more influence in preventing the general spread of the practice of disinfecting seed grain than has the cost of materials or the difficulty of the treatment itself.

Drying too slowly after treatment is likely to result in injury to germination, not only because of the danger of heating or molding, but also because of the prolonged action of the formaldehyde, hot water, or other agent used. On the farm an excellent arrangement for drying is an elevated, latticed platform covered with canvas. The wet grain is spread out on this in a layer 2 or 3 inches thick and stirred occasionally to hasten the drying. When drying conditions are bad, it is generally advisable and also more convenient to sow as soon after treating as the grain is dry enough to run freely. If the grain is too moist to feed well in some seeders or drills, this may be remedied by mixing in land plaster, which will take up the surface moisture. In the case of spring grain treated during cold weather, prompt seeding is especially desirable, because of the danger of freezing the moist grain and killing it.

Poor stands attributed to seed injury often are really due to the use of too little seed. The treated grain is always more or less swollen, and the rate of seeding must therefore be correspondingly increased. The increase required can be estimated by noting the increase in bulk of all, or of a given portion, of the seed. It usually amounts to at least one-fifth of the dry grain and may even exceed one-half if the grain is shriveled. In addition to this an increase may also be required on account of reduced germination.

Growers of grain in the arid sections of the West have found that seed is frequently injured seriously even when carefully treated. This is generally because the very dry grain has been cracked or scratched over the germ in thrashing and so is almost as readily killed by the treatment as are the smut spores. The remedy is to run the cylinder at a low rate of speed when thrashing grain to be used for seed, so as to avoid injuring it. The thrashing of seed grain should be done, if possible, when the grain is slightly damp, as from dew in the morning, for it will not then be so easily injured. If only cracked seed is available, the hot-water process will injure it less than chemical treatment.

More complaint of injury to seed grain, particularly wheat, by the chemical treatments for smut has developed in districts where the softer wheats are grown. This situation is probably the result of several factors. Under the same conditions the soft wheats are undoubtedly more liable to injury in thrashing than the hard wheats. Moreover, the likelihood of weevil injury in the South would be reflected in the effect of treatment on germination, and in addition the higher temperatures prevailing, particularly when seed for fall planting is treated in the summer, would tend to increase the action of the chemical used, and more especially of formaldehyde. Care in using cold water to make up the solution or in shortening the

time of treatment would, under such conditions, reduce but not eliminate the danger of injury.

Seed may differ in its susceptibility to injury, for several reasons. Thus, in the case of sorghums, those varieties in which the seed does not thrash out of the chaff (such as broom corn and sorgos) may be given a more severe treatment than those in which the grain is uncovered (kafir and most other grain sorghums). In fact, every lot of seed grain has its own peculiarities. One European authority, recognizing this fact, recently made arrangements for growers to send in small samples of the grain which they wished to treat. With these he experimented until he could advise the farmer exactly how to treat his seed to avoid injuring it. No such facilities are provided in this country, but those who have had difficulty with seed injury would do well to do a little experimenting for themselves. It is often a serious risk to sow treated grain without first testing it for germination and then increasing the rate of seeding as necessary to get a stand.

The seeds of the small grains may easily be tested for germination. Two dinner plates and a piece of cloth four times the size of the plates (fig. 16) are all that is needed. Wring the cloth out of clean water just dry enough so it will not drip. Fold it once and lay it on one plate. Count out 100 seeds just as they come, and place them on the cloth so the seeds do not touch each other. Fold the loose end of the cloth over the seeds and cover with the other plate. After three days, open and remove and count the sprouted seeds. Moisten the cloth if necessary and let stand two days longer. Then open and remove and count the sprouted seeds, continuing until all the seeds have either sprouted or decayed.

FIG. 16.—Homemade seed germinator: *A*, Closed; *B*, open.

If the test shows poor germination and there is reason to think the seed has not been injured by the treatment, send samples of both treated and untreated grain to your State agricultural experiment station or to the United States Department of Agriculture and ask that they be tested.

Seed grain which is low in germination because of injury by treatment is nevertheless more desirable for seeding than untreated, diseased grain. A low percentage of germination in untreated seed is generally an indication of careless handling, bad storage conditions, or old seed; in short, of reduced vitality, due oftentimes to the pres-

ence of scab and similar diseases. From such seed a good healthy stand can not be obtained, even with a heavy rate of seeding. With seed of good quality, however, which has been freed from diseases but is low in germination because of treatment that was somewhat too severe, an abundant stand of healthy plants may be obtained by increasing the rate of seeding to the required extent, as indicated by a germination test. This is especially true if the hot-water or formaldehyde methods of treatment have been used. Copper sulphate may weaken the plants if the seed is not properly limed after treatment.

DISINFECTION AND YIELD.

Yield is, of course, the first consideration in the matter of profits from the disinfection of seed grain. Careful experiments both in this country and in Europe show that the disinfection of the seed frequently increases the yield more than would be expected from simply replacing the smutted heads with sound ones. The greatest gain is usually obtained from the use of the formaldehyde or the hot-water treatment. Increases of over 4 bushels per acre have been found in spring wheat in which only a little over 1¼ bushels were actually destroyed by smut. Similarly, oats have given added yields two to five times as great as the quantity of grain which was smutted in the fields not treated. These results have been largely corroborated by the experience of county agents in demonstrations of the formaldehyde treatment for oats.

This added increase, when it occurs, is probably chiefly due to the fact that the grain is affected by other, less evident seed-borne parasites than smut,[1] which are as effectually checked as the smut by the treatment given. Barley, for instance, is affected by a disease called stripe, which can be largely controlled by the soaking treatment with formaldehyde (p. 17). In Europe treatments of seed grain are often employed when no smut is present, for the sole purpose of eliminating this type of disease and the losses caused thereby.

While smut in the cereal crops is never directly caused by any condition of the weather or soil, the amount occurring in the crop is always more or less influenced by such factors. The conditions during the growing period of the crop, particularly in the soil at seeding time, must be favorable to the smut parasite if the latter is to be successful in producing the disease, i. e., in reproducing itself. Smut losses might therefore be largely avoided if the conditions at the time of seeding could be determined beforehand. While this, of course, is impossible, early seeding for both spring and winter

[1] Rust on any of the cereals is not known to be seed borne and hence is not to be included here among those diseases which are partially or wholly prevented by seed treatment.

grains [1] will usually reduce the disease materially, and it is because of this interference of weather conditions that growers are frequently in a position to contend that their crops are not affected by smut, when, as a matter of fact, it is present every season. The grower is, of course, concerned only when he loses most of his crop, i. e., when it happens that the season has favored infection at the time of seeding and the yield is very perceptibly reduced. To avoid this risk of loss in yield he must treat his seed every year, for the presence of ever so little smut in a field is a menace to the profitable use of seed from that field for producing another crop.

It is true that community cooperation and the necessary legislation might eventually eliminate the smuts from a grain-growing district, so that treatment would not have to be repeated each season. Such a condition, however, does not now obtain in any district of which the writers have knowledge. Even if an individual farmer should succeed in producing a perfectly clean crop of grain, he would, unless isolated and using his own thrashing rig, be likely to find the disease as bad as ever in a year or two. Under such conditions the growing of varieties resistant to smut is the only way in which the necessity for treatment can be avoided, and such varieties are unfortunately not generally available for all the cereal crops or for all sections of the country.

[1] Very late spring and fall seedings frequently show less smut than those sown on an average date, but this is not of practical importance in most sections where grain is grown, since other reasons obtain for not seeding at this time.

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